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14. ABSTRACT
Air Force Research Laboratory (AFRL) has been providing support for The NASA Green Propellant Infusion Mission (GPIM) to demonstrate the in-space performance of AF-M315E monopropellant. Developed by AFRL, AF-M315E provides a higher energy density than hydrazine. AFRL support activities include: leading the definition of propellant load operations, aging of propellant tank coupons to enable propellant tank flight qualification, materials compatability verification, and establishment of an AF-M315E MIL SPEC. The initial approach for propellant load was to mimic the legacy hydrazine operations ground support equipment and procedures developed over decades and take advantage of the decreased hazards of AF-M315E where practical. The legacy hydrazine design relied on a pressurized system to transfer propellant from a bulk propellant tank into a spacecraft tank. It also called for the transfer of propellant from a large transport container into a specialized container that was integral to the loading system. A pump-fed design was chosen for AF-M315E operations to simplify design, minimize contamination risk, and enable greater precision. The final design comprises 4 propellant load discrete functional components on carts with each performing a unique task essential to the propellant loading campaign. These four carts, collectively referred to hereafter as Propellant load Ground Support Equipment (PGSE) are: the propellant load cart (PLC), the dry side tank cart (DSTC), the propellant detank cart (PDC), and the service valve manifold (SVM). The design and operations are subject to requirements from the Air Force Space Command Manual (AFSPCMAN) 91-710.In order to launch pressurized propellant tanks on a spacecraft or satellite, a fracture mechanics analysis is required to verify the safe design life of the pressure vessel in service. Fracture mechanics is the study of the influence of loading, crack size, and structural geometry on the fracture resistance of materials containing natural flaws and cracks. The objective of fracture mechanics analysis is to limit operating stresses so that a preexisting flaw of an assumed initial size will not grow to a critical size during the desired service life of a vehicle's propellant tank. Air Force Space Command Manual (AFSPCMAN) 91-710 specifies the requirements for flight propellant tank qualification. The approach being taken is to expose partially fractured bulk and weld coupons to accelerated aging within AF-M315E in an environmentally controlled oven. The approach for qualification uses the mechanism and concept proposed in ASTM E1681-03, Section 6 ("Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials"), but was modified slightly to minimize use of AF-M315E. Samples of the propellant tank material were cut, sized, and pre-cracked at NASA KSC based on ASTM E1681-03, Section 7.

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SUMMARY OF AIR FORCE RESEARCH LABORATORY SUPPORT FOR THE NASA GREEN PROPELLANT INFUSION MISSION

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INTRODUCTION

Air Force Research Laboratory (AFRL) has been providing support for The NASA Green Propellant Infusion Mission (GPIM) to demonstrate the in-space performance of AF-M315E monopropellant. Developed by AFRL, AF-M315E provides a higher energy density than hydrazine. AFRL support activities include: leading the definition of propellant load operations, aging of propellant tank coupons to enable propellant tank flight qualification, materials compatability verification, and establishment of an AF-M315E MIL SPEC.

The initial approach for propellant load was to mimic the legacy hydrazine operations ground support equipment and procedures developed over decades and take advantage of the decreased hazards of AF-M315E where practical. The legacy hydrazine design relied on a pressurized system to transfer propellant from a bulk propellant tank into a spacecraft tank. It also called for the transfer of propellant from a large transport container into a specialized container that was integral to the loading system. A pump-fed design was chosen for AF-M315E operations to simplify design, minimize contamination risk, and enable greater precision. The final design comprises 4 propellant load discrete functional components on carts with each performing a unique task essential to the propellant loading campaign. These four carts, collectively referred to hereafter as Propellant load Ground Support Equipment (PGSE) are: the propellant load cart (PLC), the dry side tank cart (DSTC), the propellant detank cart (PDC), and the service valve manifold (SVM). The design and operations are subject to requirements from the Air Force Space Command Manual (AFSPCMAN) 91-710.

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PROPELLANT GROUND SUPPORT EQUIPMENT (PGSE)

The AF-M315E tailored design for PGSE eliminates the need for transferring propellant from a shipping container into another container prior to loading. It also changed the overall

function from being a pressure-fed system to a pump-fed system. This eliminates several time consuming and involved steps that require a red crew working under stringent conditions to transfer propellant from the transport container into a separate specialized PGSE size compatible container.

The PLC design (Figure 1) directly utilizes the transport container the AF-M315E propellant is shipped in by inserting a adapter into the shipping container. This greatly simplifies operations, eliminates many involved steps and minimizes the possibility of outside contamination of the propellant under similar transfer circumstances (i.e. inside a cleanroom). The PLC's main function is to accurately measure and control the propellant transferred from the bulk container into the spacecraft. Its secondary function is to purge the PGSE of propellants once all operations have finished. It has two separate flow control panels that work in conjunction to move propellant and/or gaseous nitrogen (GN2) through the propellant system. The GN2 is regulated down to provide drive pressure for the pump, to purge AF-M315E into the PDC, and to provide a blanket pressure into the propellant shipping container.

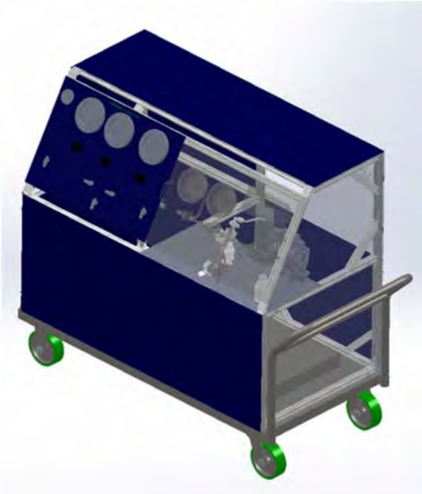

FIGURE 1: PROPELLANT LOAD CART

The DSTC, as shown in Figure 2, has two main functions: (1) to evacuate the spacecraft propellant system prior to propellant loading, and (2) to load GN2 onto the pressurant side of the spacecraft blowdown system after propellant loading. The GN2 flow control panel is very similar in design to the panel on the PLC.

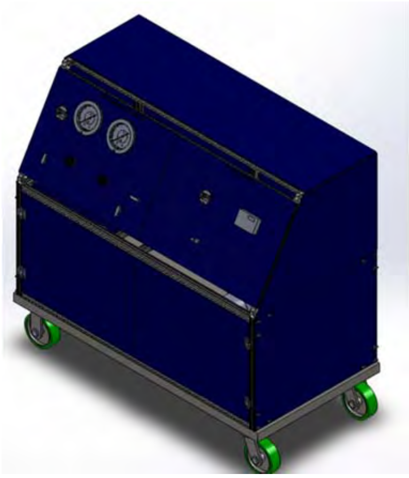

FIGURE 2: DRY SIDE TANK CART

The primary function of the PDC, as shown in figure 3, is to collect any AF-M315E that flows through the PGSE that does not go into the spacecraft. Its secondary function is to aspirate the system prior to the loading of propellant.

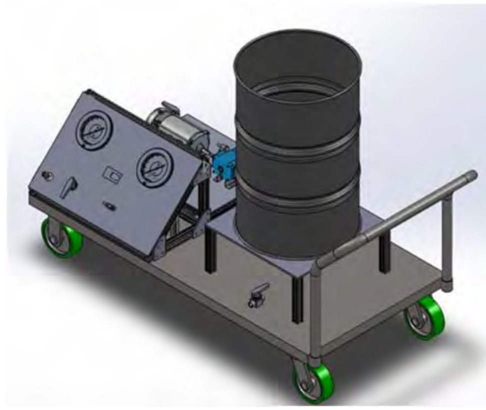

FIGURE 3: PROPELLANT DETANK CART

The final piece of the PGSE is the SVM (shown in Figure 4), whose main function is to control the flow of propellant and gas in and out of the spacecraft service valves. As a secondary function, the SVM has a side panel that contains all the components necessary to perform a point-of-delivery sampling operation. The SVM is where all the different cart systems converge. It has connections to the PLC, DSTC, PDC, and the spacecraft. It also has the main control valves for propellant and pressurant flow.

FIGURE 4: SERVICE VALVE MANIFOLD

PROPELLANT TANK COUPON FRACTURE ANALYSIS

In order to enable qualification of the propellant tank for flight, propellant tank coupons must be aged with exposure to the propellant of interest. Propellant tank specimens are fatigue pre-cracked at a stress intensity level lower than predetermined test values based upon anticipated flight requirements. Upon completion of the exposure, the specimen cracks will be inspected for evidence of growth. The specimens with stress intensity values for which there was no evidence of crack growth will be considered the threshold stress intensity values for the material.

The methodology outlined in ASTM E1681, Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials was

used. This test determines whether or not the AF-M315E weakens the metallic propellant tank upon prolonged exposure. Figures 5 and 6 show details of the experimental loading apparatus.

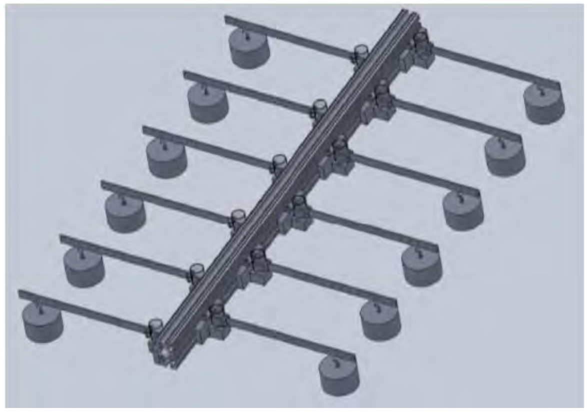

FIGURE 5: PROPELLANT TANK COUPON FRACTURE ANALYSIS EXPOSURE AND LOADING DEVICE

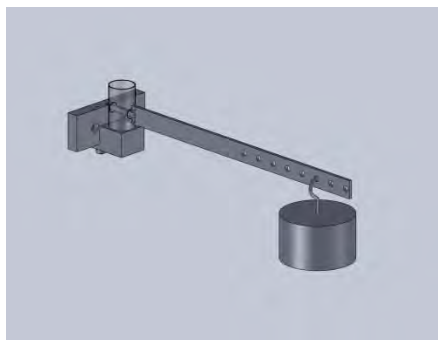

FIGURE 6: DETAIL VIEW OF PROPELLANT TANK COUPON ENCLOSURE AND LOADING ARM ARCHITECTURE

Within ASTM E1681, there are multiple options for test setup, as well as, propellant exposure durations. The exposure durations must be no less than 1000 hours at an elevated temperature of 50°C or higher to meet the requirements of the standard. Of the 3 test setup options outlined, it was decided that this test would use the cantilever option. The cantilever method is the simplest to design and build. It holds one side of the test specimen stationary while a large mass is suspended on the end of a moment arm from the other side of the specimen. The center of the specimen has a machined notch and a crack that has been intentionally grown to a specific depth from the bottom of the notch. This pre-crack is necessary to see how the propellant affects crack growth over time. Final evaluation of the propellant tank coupons has been executed by Kennedy Space Center subject matter experts.

COMPONENT MATERIAL COMPATIBILITY VERIFICATION

Part of the AF requirements by the 45th Space Test Wing at the CCAFS is conformance to Air Force Space Command Manual (AFSPCMAN) 91-710, Range Safety User Requirements, which encompasses loading operations. In preparation for the propellant loading operation, the compatibility of the propellant with all intentionally wetted parts of the Propellant load Ground Support Equipment (PGSE) must be assessed. In addition, other select materials which will not be intentionally wetted at the integration facility must be screened for suitability for short term contact in case of accidental exposure.

To that end, accelerated aging tests were performed by immersion of the materials in propellant at 60°C for a 10 week period in a similar fashion to previous testing at AFRL. The propellant was monitored for changes in pH, color, gassing, and dissolved metals if applicable. Pre- and post-test microscopy was performed on the material samples and examined for evidence of pitting or etching. Based on these results a determination of the compatibility of proposed loading cart materials with AF-M315E was made.

AF-M315E is not long-term compatible with most metallic components. Over time leaching of metals can catalyze propellant decomposition and compromise the thermal stability and storage life. For this reason it was decided to construct an AF-M315E loading cart with wetted components consisting of soft goods. Compatibility data exists for many of the polymeric materials identified as suitable materials of construction, however certain components containing proprietary formulations (e.g. greases) or uniquely processed materials (e.g. filter elements) need to be tested with the propellant. Any non-wetted PGSE material potentially exposed to the propellant was also tested by a screening of two weeks at 60°C to demonstrate whether it is a contact hazard.

AF-M315E MIL SPEC DEVELOPMENT

A military specification (Mil Spec) for the monopropellant AF-M315E is needed for the purpose of ensuring a standardized quality of the propellant procured from potential manufacturers for the peak performance and safety of all future tests and missions involving AF-M315E. The current Mil Spec draft, which used the specifications for hydrazine and liquid gun propellant as guides has been under development at the Air Force Research Lab (AFRL) at Edwards Air Force Base for several years.

Increasing interest in the propellant due to encouraging results from past and ongoing programs utilizing AF-M315E, coupled with the recent NASA funded Green Propellant Infusion Mission (GPIM) are driving the need for the Mil Spec to be finalized and approved. For the near term it is important for different laboratories to be able to adequately perform assays of the propellant to support testing and ultimately a spacecraft loading operation. Longer term, a finalized Mil Spec will be essential if the propellant production is to be transitioned from AFRL to industry. The Mil Spec will not only be used as specifications the manufacturer(s) will need to meet for production, but will also give direction to those seeking necessary tests to support operations.

Several laboratories are currently participating in an inter-laboratory study (ILS) to look at the reproducibility of the test methods contained in the current draft of the Mil Spec across several locations with different personnel, different equipment, and different conditions. The target values, along with their acceptable ranges, and the test methods for each of the properties in the current draft of the Mil Spec will be subject to change, based on the results of the study, and on the feedback from the labs on the effectiveness and feasibility of each of the test methods. Comments and recommendations from the labs participating in the ILS will be addressed and integrated into the Mil Spec document before it is submitted into the Defense Standardization Program.

SUMMARY

In support of the GPIM program AFRL has base lined designs and procedures for load operations of AF-M315E that are simplified relative to load and handling operations with hydrazine and compliant with AFSPC 91-710 requirements. In support of the load operations, component material compatibility verification and Mil Spec development have been executed to lead to finalized guides for future reference. Also, AFRL has provided critical support for propellant tank qualification with accelerated exposure aging of the propellant tank coupons. Each of these activities is critical in the technology transition of AF-M315E and represents

required data and standards establishment that would otherwise incur significant cost if left to be developed independently.